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Herpetofaunal and vegetational characterization of a thermally-impacted stream at the beginning of restoration

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Abstract

Pen Branch, a third order stream on the Savannah River Site (SRS), located near Aiken, SC, USA, received thermal effluents from the cooling system of a nuclear production reactor from 1954 to 1988. The thermal effluent and increased flow destroyed vegetation in the stream corridor (i.e. impacted portion of the floodplain), and subsequent erosion created a braided stream system with a greatly expanded delta. Restoration of the area began with planting of bottomland hardwood species in 1993. Occurrence of amphibians and reptiles was monitored by daily sampling from 1 January 1995 through 30 September 1996 to characterize the course of the restoration. Vegetation was sampled in the summer of 1996 to characterize the habitats in the unimpacted riparian zone and the impacted stream corridor. A total of 12 580 individuals representing 72 species of herpetofauna were captured. There were no significant differences in relative abundance or diversity of herpetofauna in unplanted versus planted zones within the impacted corridor 3 years after planting. Likewise, there were no significant differences in abundance or diversity of herpetofauna in the upper and lower corridor areas, which differed in site preparation before planting, or in riparian zones of different widths. However, species diversity of amphibians and reptiles in the unimpacted riparian zone was significantly higher than on vegetated islands located between stream braids within the impacted floodplain corridor. There were also significantly more species and individuals within the riparian zone than in the corridor, and the species assemblage within the riparian zone differed from that of the corridor. Woody vegetation within the unimpacted riparian zone was significantly higher in basal area than on islands within the corridor.

Keywords: Amphibians; Floodplain restoration; Herpetofauna; Reptiles; Riparian width; Species diversity

1. Introduction

Over the past three decades, US federal laws have required the protection and restoration of wetlands, and a wide range of policies also have

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been enacted at the state level. Because vegetated riparian and bottomland habitats are essential to the natural ecological functioning of associated streams, the National Research Council's Committee on Restoration of Aquatic Ecosystems, Science, Technology, and Public Policy (1992) (National Research Council, 1992) recommended that 'riparian habitat and bottomland restoration should be made a high national priority along with the restoration of the stream or river channel'.

For over 30 years, tributaries to the Savannah River on the Savannah River Site (SRS), a Department of Energy nuclear production facility located near Aiken, SC, were impacted by thermal effluents from nuclear production reactors resulting in dramatic physical and biological modifications of bottomland habitats. The stability of bottomlands is of concern because, in addition to providing forage and water for upland wildlife, riparian zones and bottomlands are important habitats for a number of wildlife species. Of the 99 amphibian and reptile species reported from the SRS (Gibbons et al., 1997), at least 80 are found in riparian and bottomland habitats (Gibbons and Semlitsch, 1991).

Although riparian zones and bottomlands provide habitats for numerous species of wildlife, wetland evaluation techniques incorporating wildlife diversity and abundance primarily have used bird species (Adamus et al., 1987; Marble, 1992). This is in spite of the fact that herpetofauna play a vital role in forest wetland ecosystems. Vickers et al. (1985) reported that in the southern United States, herpetofaunal species constitute 45% of native vertebrate fauna excluding fish. Salamander biomass in a New Hampshire study was reported to be double that of avifauna during the breeding season and almost equal to that of small mammals (Burton and Likens, 1975). Hairston (1987) estimated that the biomass of salamanders in the Appalachian forests of North Carolina may exceed that of all other vertebrates combined. Herpetofauna have been shown to be vital components of food webs (Burton and Likens, 1975; Bury and Corn, 1988; De Graaf and Rudis, 1994) and have been suggested as important indicators of habitat quality (Bury and Corn, 1988; Gibbons, 1988a; Vitt et al., 1990; Wake, 1991; Dunson et al., 1992).

The restoration of Pen Branch, a thermally-impacted tributary to the Savannah River on SRS, provided an opportunity to assess the status of herpetofauna within the impacted corridor. A study to monitor the course of restoration in the Pen Branch corridor by characterizing the herpetofauna was initiated in 1995. In this study we tested these hypotheses: (1) herpetofaunal diversity is higher in the unimpacted riparian zone than in the impacted stream corridor; (2) herpetofaunal diversity is higher in the planted zones than in the unplanted zones within the stream corridor; (3) herpetofaunal diversity is higher in the treated than in the untreated planting zones (i.e. upper and lower corridor); and (4) herpetofaunal diversity increases with riparian width.

2. Methods and materials

2.1. Study area

The site for this study is 39.5 ha of Pen Branch corridor located in the Southwest section of the SRS at an elevation of approximately 30.5 m. Annual precipitation averages 123.85 cm, and average annual temperatures range from 32.8°C in July to 1.7°C in January (Hunter and Leard, 1995). Soils in the Pen Branch corridor are fluvaquents that are frequently flooded (Rogers, 1990). The width of the riparian zone ranges from 38 to 188 m (average width, 74 m). Unpaved roads border the riparian zone, running parallel to the stream. Beyond these roads the habitat varies from clearcuts to young and mature pine and mixed hardwood stands.

Pen Branch is a third-order stream on the SRS which began receiving thermal effluent from a production reactor in 1954. During reactor operation, flow increased more than 20 times the stream's base flow rate, and thermal effluents increased stream temperatures from a normal range of 10–20 to 40–50°C (Nelson, 1996). High temperatures and high silt loads destroyed virtually all vegetation within the corridor. Wike et al. (1994) reported that canopy defoliation was apparent throughout 113 ha of the corridor by 1961. Gibbons and Semlitsch (1991) reported that Pen Branch was uninhabitable by herpetofauna throughout much of its main course when the reactor was in operation.

In 1988 the reactor was shut down, and the Record of Decision (DOE, 1991) resulting from the Continuing Reactor Operations Environmental Impact Statement (DOE, 1990) committed the SRS to develop and implement a plan to mitigate the past impacts and to restore the cypress-tupelo and bottomland hardwood wetlands of the Pen Branch corridor and delta regions. A mitigation action plan was formulated to guide restoration efforts in the Pen Branch corridor (Nichols, 1992). In 1993 the USDA Forest Service, in cooperation with the Westinghouse Savannah River Company, began restoration of the Pen Branch bottomland stream habitat by planting bottomland tree species in the corridor and delta (Davalos et al., 1996). In the upper corridor, nine species were planted, swamp chestnut oak (*Quercus michauxii* Nuttall), cherry bark oak (*Q. falcata* Michaux), water oak (*Q. nigra* L.), water hickory (*Carya aquatica* [Michaux f.] Nuttall), green ash (*Fraxinus pennsylvanica* Marshall), persimmon (*Diospyros virginiana* L.), swamp tupelo (*Nyssa sylvatica* Marshall), water tupelo (*N. aquatica* L.), and baldcypress (*Taxodium distichum* [L.] Richard). In the lower corridor, five species were planted, swamp chestnut oak, cherry bark oak, green ash, swamp tupelo, and baldcypress. The stream corridor was divided into unplanted and planted zones. Lower corridor planted zones did not receive site preparation. Planting zones within the upper corridor received application of the herbicide Rodeo® (Monsanto Company, 1990) and/or controlled burning for weed control. The USDA Forest Service provided analysis of concentrations of the herbicide in the stream under lowest flow rate at peak concentration after application and determined that exposure to aquatic vertebrates and invertebrates was below the concentration allowed by the USDA Forest Service (1989) and presented no harmful effect.

Silt islands deposited within the Pen Branch corridor during reactor operation now divide the stream into two major channels with several smaller intermittent channels braided into the stream system. Early successional woody plants such as red maple (*Acer rubrum* L.), wax myrtle (*Myrica cerifera* L.), and black willow (*Salix nigra* Marshall) and a number of herbaceous species including false nettle (*Bohermia cylindrica* [L.] Swartz) now cover the corridor which once had flourished with large canopy trees typical of bottomland hardwood habitats. From the upper corridor to the delta, vegetation plots alternated between unplanted and planted strips. There were six unplanted strips ($n = 6$) with a total area of 9.4 ha, and six planted strips ($n = 6$) with a total area of 30.1 ha.

2.2. Herpetofaunal sampling

To sample herpetofauna, 11 trap lines were established, five in unplanted areas and six in planted areas. Because the upper corridor was larger (24.2 ha) than the lower corridor (15.3 ha), the upper corridor contained seven trap lines (3.5/ha) and the lower corridor four (3.8/ha).

2.3. Trapping methods

Each trap line consisted of one drift fence with pitfall traps (Gibbons and Semlitsch, 1981), eight arrays of coverboards (Grant et al., 1992), two turtle traps, and three minnow traps. Animals also were collected opportunistically by hand along trap lines. Drift fences were placed at the edge of the upland forest areas approximately 14 m from and parallel to the stream so as to be above flood level (drift fences were not used within the floodplain because of periodic flooding and high water tables). Fences were constructed with aluminum flashing approximately 30×0.6 m, buried 10 cm in the ground. Metal buckets (19 l, approximately 30 cm in diameter and 40 cm deep), each containing a moistened sponge, were buried flush with the ground on each side of the fence at 7.6 m intervals and were checked daily for captures for the entire 21 month sampling period.

Coverboards were deployed in arrays of four boards (two plywood and two stainless steel) each measuring 0.61 × 1.22 m. Coverboards provided cover for animals and were checked by lifting one side of the board and capturing any animal found underneath. Riparian arrays (RA) were set randomly on both sides of the stream at the edge of the upland habitat and on the stream banks. Island arrays (IA) were distributed randomly on the islands between the stream braids within the floodplain along a general trap line that ran perpendicular to the bank. There were four RA's per line and four IA's per line. All coverboard arrays were checked daily for the entire 21-month sampling period.

Turtle traps were aquatic hoop nets (0.9 m hoops; 4.0 cm mesh) placed so as not to be completely submerged and parallel to the water's edge in the two main stream channels, with the funnel opening facing downstream. Funnel minnow traps (0.6 cm mesh) were placed randomly either in shallow sections of the two main channels or in smaller intermittent channels. There were two turtle traps and three minnow traps per trap line, each baited with sardines and checked for 7 consecutive days once each month during the entire 21 month sampling period.

2.4. Marking techniques

Lizards, salamanders, frogs and toads were marked by toe clipping for recapture information only, not for individual identification (Ferner, 1979). Animals captured at drift fences were released on the opposite side of the fence so they could continue on their probable original path. Animals caught underneath coverboards were replaced beneath boards. Captured turtles were taken to the University of Georgia's Savannah River Ecology Lab (SREL) for permanent marking (Gibbons, 1988b). Captured snakes were taken to a mobile lab located on site where they were marked by ventral scale clipping (Brown and Parker, 1976) for individual identification. Marked turtles and snakes were released at the capture site. Recaptures were recorded but not included in the statistical analyses for this paper.

2.5. Vegetation sampling

In the summer of 1996, a ground survey was conducted to determine vegetation characteristics of the study area. For the purpose of analysis, vegetation was grouped into overstory (trees with dbh > 10 cm), midstory (trees and shrubs with dbh 1–10 cm), and ground cover. In the riparian zone, overstory vegetation was sampled in a 0.04 ha circular plot established at the center of each drift fence. Midstory vegetation was sampled in a 0.01 ha circular plot also established at the center of each drift fence. Groundcover was sampled within four 1-m^2 plots located at distances of 2 and 4 m on each side and perpendicular to the center of each drift fence. Number of stems per ha was used to determine dominant groundcover species.

To sample vegetation within the stream corridor, two random sample circular plots were established at the center of a coverboard array on islands in the stream floodplain in each trap line. Overstory and midstory vegetation were sampled using the methods described above. Basal area (BA, m^2/ha) of overstory and midstory stems was calculated to determine the most dominant species per plot. Visual percentages of dominant groundcover species were estimated for the area surrounding the coverboard array to a distance of 5 m.

2.6. Statistical analyses

Differences in abundances of herpetofauna between the upper and lower corridor, between vegetation zones, between the riparian zone and floodplain islands, and between narrow and wide riparian zones were tested using contingency tables with associated χ^2 tests. Comparisons of species diversity were made by calculating a species diversity index (Shannon, 1948), a species evenness index (Pielou, 1969), and a species richness index (Margalef, 1958) for each of these areas. The t-test (Brower et al., 1990) was employed to test differences in the diversity indices. The Pearson product-moment correlation coefficient (Pearson, 1901) was computed to test the correlation of riparian width and herpetofaunal species abundance. The Sørensen similarity coefficient (Sørensen, 1978, as cited in Brower et al., 1990) was computed to test the resemblance of herpetofaunal species composition in the unimpacted riparian zone and the impacted floodplain communities. Since this coefficient does not take into account the relative abundances of species, the percentage of similarity (proportional similarity, Brower et al., 1990) between the unimpacted riparian zone and impacted floodplain herpetofaunal species assemblages also was determined.

3. Results

3.1. Vegetation

Plant species composition and structure in the riparian zone and floodplain islands in Pen Branch contrasted dramatically. Overstory stratum of the riparian zone consisted of typical bottomland hardwood species (Table 1) with an average basal area of 28.4 m^2/ha (Table 2). Island overstory stratum was predominantly black willow (*Salix nigra* Marshall) (Table 1) with an average basal area of 1.98 m^2/ha (Table 2).

Table 1
Predominant plant species occurring in the overstory (DBH > 10 cm) and midstory (DBH 1–10 cm) of the riparian zone and floodplain islands of Pen Branch, SRS, SC, in the summer, 1996

Riparian zone			Floodplain islands		
Species	Basal area (m^2/ha)	% Occur	Species	Basal area (m^2/ha)	% Occur
Upper corridor					
Overstory (DBH > 10 cm)					
Quercus nigra L.	43.15	26	*Salix nigra* Marshall	7.33	45
Carya glabra (Miller) Sweet	33.13	21	*Acer rubrum* L.	6.8	41
Pinus taeda L.	28.23	17	*Platanus occidentalis* L.	2.32	14
Quercus laurifolia Michaux	26.33	16	Total	16.45	100
Other	36.08	20			
Total	166.92	100			
Midstory (DBH 1–10 cm)					
Q. nigra	1.36	7	*S. nigra*	21.36	58
C. glabra	10.49	53	*Alnus serrulata* (Aiton) Willd.	6.77	18
Liquidambar styraciflua L.	1.73	9	*Myrica cerifera* L.	5.21	14
Carpinus caroliniana Walter	1.15	6	*Cephalanthus occidentalis* L.	1.36	4
Other	5.2	25	Other	2.33	7
Total	19.93	100	Total	37.03	100
Lower corridor					
Overstory (DBH > 10 cm)					
Q. laurifolia	39.75	28	None	N/A	N/A
Q. nigra	35.7	25			
P. taeda	29.63	21			
L. *styraciflua*	18.25	13			
Other	20.12	13			
Total	143.45	100			
Midstory (DBH 1–10 cm)					
L. styraciflua	2.77	53	*S. nigra*	23.8	97
Ulmus spp.	1.34	9	*C. occidentalis*	0.54	2
Q. nigra	0.66	7	*A. serrulata*	0.17	<1
Ilex opaca Aiton	0.55	6	*Quercus* spp.	0.01	<1
Other	0.66	25	Total	24.52	100
Total	5.98	100			

Table 2
Relative vegetation cover within each planting zone (trap line) in the riparian zone and on the floodplain islands, Pen Branch, Savannah River Site, SC, in the summer, 1996

Planting zone	Riparian zone			Floodplain islands	
	Basal area (m^2/ha)		Groundcover (stems per hectare)	Basal area (m^2/ha)	
	Overstory	Midstory		Overstory	Midstory
Upper corridor					
IA	20.28	2.55	39 000	5.43	7.41
IIA	17.55	1.95	33 000	3.18	0.66
VIA	16.63	6.51	56 000	1	13.88
IB	26.1	2.37	62 000	0.58	0.02
IIB	29.4	3.02	40 000	1.68	0.02
IIIB	17.98	1.1	92 000	4.13	10.59
IVB	40.98	2.43	58 000	0.45	4.45
Average ($n = 7$)	24.13	2.85	54 286	2.35	5.29
Lower corridor					
IIIA	31.45	0.26	76 000	0	4.62
IVA	36.8	1.51	65 000	4.43	10.52
VA	36.85	1.61	43 000	0.45	4.69
VB	38.35	2.6	91 000	0.45	4.69
Average ($n = 4$)	35.86	1.5	68 750	1.33	6.13
Overall avg. ($n = 11$)	28.4	2.36	59 545	1.98	5.6

Midstory stratum of the riparian zone generally consisted of the same species as the overstory but basal area was much lower (2.36 m^2/ha) for this stratum (Table 2). On islands the midstory stratum was dominated by black willow with more shrub species (Table 1). Average basal area was 5.60 m^2/ha (Table 2), over twice the midstory basal area for the riparian zone.

Riparian zone groundcover consisted mostly of greenbriar (*Smilax* spp.), panic grass (*Panicum* spp.), partridgeberry (*Mitchella repens* L.), muscadine (*Vitis rotundifolia* Michaux), *Vaccinium* spp., and yellow jasmine (*Gelsimium sempervirens* [L.] Aiton). Rushes (*Juncus* spp.), panic grass (*Panicum* spp.) and blackberry (*Rubus* spp.) formed the dominant groundcover on the floodplain islands. Although groundcover density was not measured on islands, visual percentage estimates indicated that the groundcover was more dense than that in the riparian zone.

There also were differences in groundcover vegetation composition between islands in the upper corridor and those in the lower corridor. The upper corridor was farthest from the delta, at a slightly higher elevation, and with a lower water table creating a drier, sandier habitat with blackberry dominating the groundcover vegetation; in some areas it was impenetrable. In contrast, the lower corridor was located closer to the delta, had a higher water table and fewer islands, and supported mostly wetland species dominated by panic grass and rushes. Blackberry was not recorded in the lower corridor. Black willow was dominant in the overstory and midstory of both areas.

There were no significant differences between basal area in the upper and lower corridor or between the control and treated zones. However, there was a significantly higher basal area of overstory and midstory vegetation in the riparian zone than on the floodplain islands. Basal area averaged 30.8 m^2/ha in the riparian zone and only 7.7 m^2/ha on the islands.

3.2. Herpetofauna

From 1 January 1995 to 30 September 1996 a total of 12 580 individual amphibians and reptiles representing 72 species was captured (Table 3).

Total captures equaled 15 055, of which 12% ($n = 1789$) were recaptures and 5% ($n = 686$) were not identified to species or escaped before identification.

Amphibians comprised 84.9% of the total captures (Table 3). There were 16 frog and toad species ($n = 8788$; 69.9% of total captures) and 13 salamander species ($n = 1881$; 15.0% of total captures). The eastern narrowmouth toad (*Gastrophryne carolinensis*) was the most frequently captured frog species (44.0% of frogs captured), followed in abundance by the southern toad (*Bufo terrestris*) (26.2%) and the southern leopard frog (*Rana utricularia*) (23.8%). The marbled salamander (*Ambystoma opacum*) was the most frequently captured salamander (45.3% of salamanders captured), followed by the slimy salamander (*Plethodon glutinosus*) (39.4%).

Forty-two reptile species comprised only 15.2% ($n = 1911$) of the total captures. Twenty-four snake species represented 57.1% of the total number of species captured but only 5.0% of the total individuals captured ($n = 626$). Nine lizard species ($n = 797$) represented 6.3% of the captures, and nine turtle species ($n = 487$) represented 3.9% of the captures. The banded water snake (*Nerodia fasciata*) was the most frequently captured snake (16.6% of snakes captured) followed in abundance by the redbelly snake (*Storeria occipitomaculata*) (14.4%) and the brown snake (*Storeria dekayi*) (11.8%). The green anole (*Anolis carolinensis*) was the most frequently captured reptile (35.5% of lizards captured); the five-lined skink (*Eumeces fasciatus*) was the second most numerous lizard (22.3%). The yellowbelly slider (*Trachemys scripta*) was the most frequently captured turtle (55.4% of turtles captured) followed in abundance by the common snapping turtle (*Chelydra serpentina*) (21.8%).

Successful reproduction was documented for 48 species (67% of the species assemblage) as determined by the presence of larvae, recent metamorphs, hatchlings, or newborns (see Table 3). Breeding males of seven additional frog species were heard calling from the corridor, but successful reproduction was not documented.

3.3. Seasonal captures by vegetation zones

There were no significant differences in number of animals captured between the upper corridor and lower corridor for any season in 1995. In 1996, there were no differences except for summer when significantly more individuals were caught in the upper corridor than in the lower corridor. For both years combined, there was no significant difference in number of animals captured between the upper and lower corridors. There were no significant differences in species diversity (H') of herpetofauna in the upper and lower corridors in any season or in the combined years (Table 4).

There were no significant differences in number of animals captured between the control and treated planting zones in any season. There were no significant differences in number of amphibians caught in the two different zones for 1995 or 1996. However, in 1995 there were significantly more reptiles caught in treatment zones than in control zones. There were no significant differences in species diversity (H') of herpetofauna in the control and treated planting zones in any season or in the combined years (Table 4).

3.4. Riparian zone width and species abundance and diversity

Data from drift fences were used to correlate number of species captured and width of the riparian zone (narrow zones < 60 m and wide zones > 60 m). Pearson product-moment correlation coefficients showed a negative, but weak, correlation ($r = -0.404$, $P = 0.062$) between species abundance and riparian width. There was no significant difference in species diversity between zones of different widths.

3.5. Riparian versus floodplain island herpetofauna

Coverboards were equally available to herpetofauna within the riparian zone and on floodplain islands within the Pen Branch system. However, use of coverboards by herpetofauna within these habitats was different (see Table 3). A total of 37 species ($n = 610$ individuals) were captured within

Table 3
Number of individual amphibians and reptiles collected at Pen Branch, SRS, January 1, 1995–September 30, 1996[a]

		R	*I*	*P*	*M*	*T*	*H*	Total
Salamanders								
[b]*Ambystoma maculatum* (Shaw)	Spotted salamander	0	0	30	0	0	1	31
[b]*A. opacum* (Gravenhorst)	Marbled salamander	27	1	821	0	0	4	853
[b]*A. talpoideum* (Holbrook)	Mole salamander	2	1	120	0	0	0	123
Amphiuma means Garden	Two-toed amphiuma	0	0	0	2	0	0	2
Desmognathus auriculatus (Holbrook)	Southern dusky salamander	2	0	0	0	0	0	2
[b]*Eurycea cirrigera* (Green)	Southern two-lined salamander	1	3	0	0	0	0	4
E. longicauda guttolineata (Hoolbrook)	Three-lined salamander	34	5	5	0	0	0	44
E. quadridigitata (Holbrook)	Dwarf salamander	0	1	1	0	0	0	2
[b]*Notophthalmus viridescens* (Rafinesque)	Eastern red-spotted newt	0	0	4	0	0	0	4
[b]*Plethodon glutinosus* (Green)	Slimy salamander	195	2	540	0	0	5	742
[b]*Pseudotriton montanus* Baird	Mud salamander	0	0	1	0	0	0	1
[b]*Siren intermedia* Barnes	Lesser siren	3	0	0	67	0	0	70
[b]*S. lacertina* Linnaeus	Greater siren	0	0	0	2	1	0	3
Total		264	13	1522	71	1	10	1881
Frogs and toads								
[b]*Acris gryllus* (LeConte)	Southern cricket frog	7	3	10	0	0	7	27
[b]*Bufo terrestris* (Bonnaterre)	Southern toad	34	13	2218	0	0	35	2300
[b]*Gastrophryne carolinensis* (Holbrook)	Eastern narrowmouth toad	19	4	3844	0	0	2	3869
Hyla avivoca Viosca	Bird-voiced treefrog	0	0	2	0	0	0	2
H. chrysoscelis Cope	Cope's gray treefrog	0	0	1	0	0	1	2
H. cinerea (Schneider)	Green treefrog	3	4	1	1	0	9	18
H. femoralis Bosc	Pine woods treefrog	0	0	1	0	0	3	4
H. squirella Bosc	Squirrel treefrog	0	0	0	0	0	1	1
[b]*Pseudacris crucifer* (Wied)	Spring peeper	2	0	0	1	0	1	4
P. nigrita (LeConte)	Southern chorus frog	0	0	5	0	0	0	5
P. ocularis (Bosc & Daudin)	Little grass frog	0	0	0	0	0	1	1
[b]*P. ornata* (Holbrook)	Ornate chorus frog	0	0	5	0	0	0	5
[b]*Rana catesbeiana* Shaw	Bullfrog	3	5	42	11	6	2	69
[b]*R. clamitans* Latreille	Bronze frog	41	21	275	7	0	7	351
[b]*R. utricularia* Harlan	Southern leopard frog	19	20	2032	6	0	16	2093
Scaphiopus holbrookii (Harlan)	Eastern spadefoot	0	0	37	0	0	0	37
Total		128	70	8473	26	6	85	8788
Turtles								
[b]*Chelydra serpentina* (Linnaeus)	Common snapping turtle	0	2	36	0	60	8	106
Clemmys guttata (Schneider)	Spotted turtle	0	0	0	0	4	1	5
[b]*Kinosternon baurii* (Garman)	Striped mud turtle	0	0	24	2	0	6	32
[b]*K. subrubrum* (Lacepede)	Eastern mud turtle	1	0	12	1	4	12	30
[b]*Pseudemys concinna* (LeConte)	Eastern river cooter	0	0	1	0	1	1	3
[b]*P. floridana* (LeConte)	Florida cooter	0	0	1	0	7	3	11
[b]*Sternotherus odoratus* (Latreille)	Common musk turtle	0	0	0	2	13	3	18
[b]*Terrapene carolina* (Linnaeus)	Eastern box turtle	0	0	3	0	0	9	12
[b]*Trachemys scripta* (Schoepff)	Yellowbelly slider	0	0	10	1	239	20	270
Total		1	2	87	6	328	63	487
Alligators								
Alligator mississippiensis (Daudin)	American alligator	0	0	0	0	2	0	2
Lizards								
[b]*Anolis carolinensis* (Voigt)	Green anole	53	11	154	0	0	65	283
Cnemidophorus sexlineatus (Linnaeus)	Six-lined racerunner	0	0	19	0	0	0	19
Eumeces fasciatus (Linnaeus)	Five-lined skink	27	1	148	0	0	2	178
[b]*E. inexpectatus* Taylor	Southeastern five-lined skink	2	1	20	0	0	0	23

Table 3 (*Continued*)

		R	*I*	*P*	*M*	*T*	*H*	Total
[b]*E. laticeps* (Schneider)	Broad-headed skink	25	2	96	0	0	1	124
Ophisaurus attenuatus Cope	Slender glass lizard	0	0	1	0	0	0	1
[b]*O. ventralis* (Linnaeus)	Eastern glass lizard	0	1	4	0	0	0	5
[b]*Scincella lateralis* (Say)	Ground skink	27	0	80	0	0	6	113
[b]*Sceloporus undulatus* (Bosc & Daudin)	Eastern fence lizard	3	0	39	0	0	9	51
Total		137	16	561	0	0	83	797
Snakes								
[b]*Agkistrodon piscivorus* (Lacepede)	Eastern cottonmouth	0	4	1	2	0	36	43
[b]*Carphophis amoenus* (Say)	Eastern worm snake	2	0	17	0	0	0	19
[b]*Cemophora coccinea* (Blumenbach)	Scarlet snake	3	0	28	0	0	0	31
[b]*Coluber constrictor* Linnaeus	Black racer	4	5	4	0	0	21	34
Crotalus horridus Linnaeus	Timber rattlesnake	0	0	0	0	0	3	3
[b]*Diadophis punctatus* (Linnaeus)	Southern ringneck snake	14	3	13	0	0	1	31
Elaphe guttata (Linnaeus)	Corn snake	0	0	1	0	0	1	2
E. obsoleta (Say)	Rat snake	0	0	0	0	0	8	8
[b]*Farancia abacura* (Holbrook)	Mud snake	2	6	8	1	0	0	17
[b]*F. erytrogramma* (Latreille)	Rainbow snake	6	4	27	2	0	1	40
Heterodon platirhinos Latreille	Eastern hognose snake	0	0	0	0	0	1	1
H. simus (Linnaeus)	Southern hognose snake	0	0	1	0	0	1	2
[b]*Lampropeltis getula* (Linnaeus)	Eastern kingsnake	6	2	0	0	0	6	14
[b]*L. triangulum elapsoides* (Holbrook)	Scarlet kingsnake	0	0	1	0	0	1	2
[b]*Nerodia erythrogaster* (Forster)	Redbelly water snake	8	5	4	3	0	7	27
[b]*N. fasciata* (Linnaeus)	Banded water snake	11	37	30	18	1	7	104
N. taxispilota (Holbrook)	Brown water snake	2	1	0	15	1	13	32
[b]*Opheodrys aestivus* (Linnaeus)	Rough green snake	1	0	2	0	0	5	8
[b]*Storeria dekayi* (Holbrook)	Brown snake	11	22	40	0	0	1	74
[b]*S. occipitomaculata* (Storer)	Redbelly snake	6	0	80	0	0	4	90
Tantilla coronata Baird & Girard	Southeastern crowned snake	0	0	4	0	0	0	4
[b]*Thamnophis sauritus* (Linnaeus)	Eastern ribbon snake	3	7	4	0	0	5	19
[b]*T. sirtalis* (Linnaeus)	Eastern garter snake	1	3	6	0	0	9	19
Virginia striatula (Linnaeus)	Rough earth snake	0	0	1	0	0	0	1
Total		80	99	272	41	2	131	625
Grand total		610	200	10 915	144	339	372	12 580

[a] *R*, number captured under coverboards in unimpacted riparian zone; *I*, number captured under coverboards on floodplain islands; *P*, number captured in pitfall traps; *M*, number captured in minnow traps; *T*, number captured in turtle traps; and *H*, hand captures.
[b] Reproduction documented by the presence of larvae, hatchlings, recent metamorphs, or juveniles.

the riparian zone, but only 31 species ($n = 200$ individuals) were captured on the floodplain islands. Ten species were captured only in the riparian zone, four were captured only on the floodplain islands, and 27 were captured in both habitats. The Sørensen similarity coefficient, which measured the similarity of herpetofaunal species composition in the unimpacted riparian zone and the impacted floodplain, was 0.7941. However, the percentage of similarity (or proportional similarity) which takes into account the relative abundances of the various species, was only 0.4610.

Species diversity was significantly higher in the riparian zone for 1996. Additionally, species richness was higher in the riparian zone in 1995, 1996, and in combined years. Evenness, however, was higher on the islands in 1995, 1996, and 1995–1996 in combined years (Table 5).

4. Discussion

The results of this study indicate significant colonization of the Pen Branch corridor by amphibians and reptiles. Of 99 species reported occurring on the SRS, 72 were collected in this study. By comparison, a herpetofaunal survey of Four Holes Swamp, SC (Hall, 1994), documented a total of 62 species. Habitats sampled in that study resembled the bottomland hardwood and cypress swamp habitat that once existed along the Pen Branch corridor.

Successful reproduction by 67% of the species indicates the wetland in its current stage of development is functioning to provide suitable habitat and that populations appear to be established. It is probable that colonization by aquatic herpetofauna and amphibians, which breed within the corridor has occurred since the reactor shut-down in 1988. Few studies have documented the effects

Table 4
Seasonal and overall species diversity by vegetational zone in the Pen Branch corridor, SRS, as measured by Shannon's species diversity (H'), Margalef's species richness (S), and Pielou's species evenness (J') indices

	Upper corridor			Lower corridor		
	H'	S	J'	H'	S	J'
January–March 1995	2.26	18.67	0.78	2.53	20.25	0.84
April–June 1995	1.91	27.50	0.58	1.78	28.50	0.53
July–September 1995	1.70	19.86	0.57	1.80	22.25	0.58
October–December 1995	2.08	12.57	0.83	2.33	15.50	0.86
January–March 1996	1.85	12.29	0.74	2.28	15.50	0.85
April–June 1996	2.21	24.29	0.70	2.54	25.00	0.79
July–September 1996	2.33	19.57	0.79	2.25	19.25	0.77
January 1995–September 1996	2.37	44.43	0.62	2.35	46.50	0.61
	Treated planting zone			Untreated planting zone		
	H'	S	J'	H'	S	J'
January–March 1995	2.23	17.25	0.79	2.34	21.50	0.76
April–June 1995	1.91	27.00	0.58	1.91	28.50	0.57
July–September 1995	1.72	19.25	0.58	1.68	20.67	0.57
October–December 1995	2.07	11.50	0.86	2.10	14.00	0.80
January–March 1996	1.77	12.50	0.70	1.95	12.00	0.80
April–June 1996	2.29	23.00	0.74	2.10	26.00	0.64
July–September 1996	2.36	20.25	0.78	2.30	18.67	0.79
January 1995–September 1996	2.30	44.25	0.61	2.39	44.67	0.63

Table 5
Species diversity in floodplain islands and in the riparian zone of the Pen Branch corridor, SRS, as measured by Shannon's species diversity (H'), Margalef's species richness (S), and Pielou's species evenness (J') indices

	Floodplain islands			Riparian zone		
	H'	S	J'	H'	S	J'
January 1995–December 1995	1.63	5.82	0.95	1.93	11.50	0.79
January 1996–September 1996	1.41	5.18	0.94	1.88	8.82	0.88
January 1995–September 1996	1.52	5.50	0.94	1.91	10.20	0.84

of thermal effluents on herpetofauna in these habitats. Most of the literature addressing ther-mally-impacted water systems concern impacted impoundments on the SRS, and most focus on physiological and behavioral responses of selected species to elevated water temperatures (Gibbons, 1970; Christy et al., 1974; Murphy and Brisbin, 1974; Nelson, 1974). High mortality of toad eggs and embryos resulted when eggs were deposited in sites that exceeded a maximum thermal limit of approximately 33°C (Volpe, 1953). However, both reptiles and amphibians showed increased growth rates in areas warmed only a few degrees above ambient (Christy et al., 1974; Nelson, 1974). Although it is possible that aquatic or aquatic-breeding herpetofauna may have inhabited cooler adjacent seepage areas, small tributaries or lower reaches of the delta during reactor activity, the 40–50°C discharge and 20-fold increase in flow rate precluded permanent occupation of the Pen Branch floodplain for over 30 years.

It appears the planting treatment regimes within the impacted floodplain have had no impact on the early successional herpetofaunal species assemblage. Three years after burning and herbicide application, comparisons of herpetofaunal species diversity showed no significant differences in herpetofauna using these areas as compared to unplanted zones. Likewise, there were no significant differences in species diversity in the upper and lower corridor. This was not surprising, because most of the species captured within the impacted floodplain were either aquatic species or those known to inhabit a wide variety of wetland habitats, including areas that have been heavily disturbed. Since amphibians may have effective migratory distances up to 1000 m (Gibbs, 1993), it is also possible that the scale of the treatments is too small for differences in herpetofaunal diversity between treatments to be measured.

Recent studies have shown amphibian and reptile abundance to be greater in streamside habitats than in upland habitats, but species richness was not found to be significantly different (Bury, 1988; McComb et al., 1993; De Graaf and Rudis, 1994; Dupuis et al., 1995). Dupuis et al. (1995) showed that riparian habitats are vital to upland herpetofauna, but upland habitats also are important to aquatic species. According to Hairston (1987), some aquatic amphibians will forage in upland forested habitats for food. Many reptiles use aquatic habitats for food and cover but move to upland sites for nesting (Wigley and Roberts, 1994). Burke and Gibbons (1995) estimated that a 275 m zone surrounding a wetland habitat should be protected to adequately preserve turtle nesting habitat.

Rudolph and Dickson (1990) found a direct correlation between riparian zone width and abundance of herpetofauna; significantly fewer reptiles and amphibians were found in narrow riparian strips (0–25 m) than in wide riparian strips (50–95 m). In this study there were no significant differences in species diversity between zones of different widths, and there was a negative, but weak, correlation between riparian zone width and species abundance. However, all riparian zones in our study were relatively wide (38–188 m) and exceeded Rudolph and Dickson (1990) recommended minimum riparian zone width of 30 m. In addition, whereas the upland habitats in Rudolph and Dickson's (Rudolph and Dickson, 1990) study were uniformly young pine plantations (vegetation heights generally < 2 m), upland habitats beyond the riparian zone at Pen Branch vary from recent clear-cuts to mature pine stands. These upland habitats may influence species composition and abundance within adjacent riparian areas differently, regardless of the widths of those zones.

The ecological importance of the unimpacted riparian zone in the recovery of the impacted floodplain of Pen Branch is borne out by the similarity of the species assemblages of the two areas. A Sørenson coefficient (quotient of similarity) of 0.7941 indicates a relatively high level of species overlap. However, this statistic does not take into account the relative abundances of species. Relative abundance values and a percentage of similarity (proportional similarity) of only 0.4610 confirm that, at the present stage of vegetational development, the impacted floodplain does not support the density of herpetofauna of the surrounding unimpacted riparian zone. In addition, species preferring a closed canopy, deep litter layer, or sparse groundcover (e.g. *Desmognathus auriculatus*, *Sceloporus undulatus*, and *Carphophis amoenus*) were found only in the unimpacted riparian zone in which these conditions prevailed and there was significantly higher overstory and midstory basal areas of vegetation. Although quite different in hydrology, the islands resemble recently cutover sites in that there is little leaf litter and primary successional plant species dominate. Reptile species found to be more abundant on the floodplain islands than in the riparian zone were either aquatic snake species or those known to inhabit open, disturbed sites (e.g. *N. fasciata*, *Agkistrodon piscivorus*, *Farancia abacura*, *Thamnophis sauritus*, and *S. dekayi*). The most abundant amphibians on the floodplain islands (*Rana clamitans*, *R. utricularia*, and *B. terrestris*), although less abundant than in the riparian zone, are also species known to inhabit disturbed wetland sites.

Vegetation and herpetofaunal data indicate that the Pen Branch corridor is in a very early stage of recovery. However, the unimpacted riparian zone is sufficiently rich in herpetofauna to provide a source for continued reptile and amphibian recolonization of the impacted floodplain islands. We predict that as the plant community within the corridor develops into a mature forest, the herpetofaunal community within the corridor will more closely resemble that of the surrounding riparian zone.

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